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## Concise Papers

### Hybrid D-PCM, A Combination of PCM and DPCM

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**Abstract**—After a short review of the basic principles of PCM and DPCM coding it is shown that combining the two methods in one coding system results in a combination of some favorable properties. The hybrid D-PCM system combines the bit-rate reduction of DPCM with a low error sensitivity. In another approach the hybrid D-PCM system is also derived from a usual DPCM system with a leaking integrator. Two different applications of the hybrid D-PCM system illustrate the possibilities and the performance of the hybrid D-PCM system.

#### 1. INTRODUCTION

The most obvious method for the digital encoding of television signals is linear pulse code modulation or PCM. However for the transmission or storage of a digitized television signal it is desirable to reduce the number of bits of the encoded signal as much as possible without losing too much relevant information. A rather efficient method, which can be implemented quite simply, is differential PCM or DPCM.

In a PCM system the incoming signal is sampled and the amplitude of each sample is measured with a fixed scale, as illustrated in fig. 1. The distinct levels on the scale can have a linear or a nonlinear distribution and they are numbered in order, starting with a fixed zero-level. The amplitude of each sample is digitized by rounding off its amplitude to the nearest distinct scale level (quantizing) and assigning the appertaining number to the sample.

These numbers can be processed or transmitted and each number is easily reconverted in the PCM decoder to a sample amplitude that corresponds to the original quantized level on the measuring scale. When a transmission error in the case of a digitized television signal results in a wrong number at the decoder, the decoded picture shows only one wrong picture element on the display, which in general is not very disturbing.

In a DPCM system the amplitude of the incoming samples is measured with a sliding scale, as illustrated in fig. 2. Here the zero level of the scale is put at the quantized amplitude of the previous sample and the distinct levels on the scale are again numbered in order. Each sample amplitude is then measured

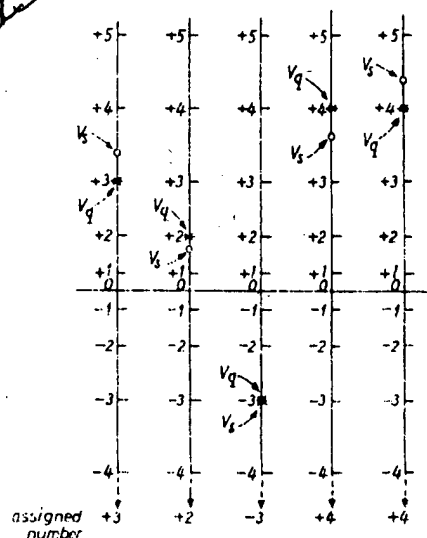


Fig. 1. Principle of PCM coding: quantizing and coding with a fixed measuring scale.

$V_s$  = sampled signal amplitude  
 $V_q$  = quantized sample amplitude

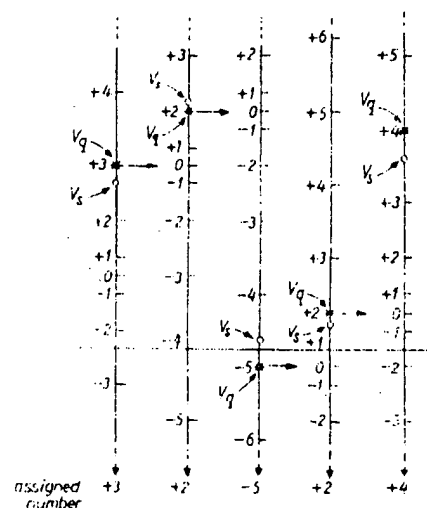


Fig. 2. Principle of DPCM coding: quantizing and coding with a sliding measuring scale. The zero of the scale is determined by the quantized amplitude of the previous sample.

$V_s$  = sampled signal amplitude  
 $V_q$  = quantized sample amplitude

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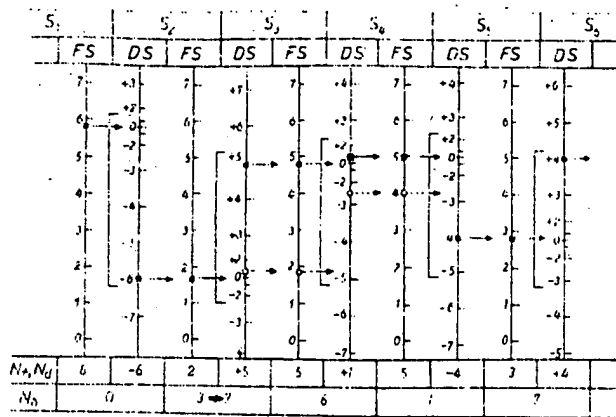


Fig. 4. Error correction of hybrid D-PCM coding; the error is made at the transmission of  $S_3$ .

FS, DS,  $N_f$ ,  $N_d$ ,  $N_h$  = fig. 3.

\* = actual sample amplitude (partly erroneous).

○ = correct sample amplitude (when the actual sample amplitude is erroneous).

difference signal, which again is added to the amplitude of sample  $S_2$ , resulting in the amplitude of sample  $S_3$ . In this way all sample amplitudes are reconstructed from the incoming sequence of numbers.

From the foregoing it appears that the recovery of the difference number  $N_d$  in the decoder does not depend on the actual value of the PCM number  $N_f$ , as long as in the encoder and the decoder the same numbers  $N_f$  occur (encoder:  $N_h = N_f + N_d \Rightarrow$  decoder:  $N_d = N_h - N_f$ ). This means that the accuracy of the signal reconstruction in the decoder is independent of the kind of quantization of the previous sample amplitude that is used to obtain  $N_f$ . So for the reconstruction we can tolerate indeed a very coarse fixed scale FS, as the one used in the example of fig. 3. The choice of the scale FS only influences the error correction (section 2.3) and the limitation of  $N_d$  (section 2.4).

### 2.3 The error correction

Fig. 4 shows the response of the hybrid D-PCM decoder of fig. 3 to a transmission error. It is assumed that the second number  $N_{h2} = 3$  is received as  $N_{h2} = 7$ , which corresponds to an inversion of the most significant bit. In exactly the same way as in fig. 3 the sequence of the reconstructed sample amplitudes can be obtained from the incoming sequence of numbers  $N_h$ . For easy comparison the correct sample amplitudes are indicated in fig. 4 with small circles and dashed arrows. In this example the bit error is corrected completely after only two sample periods, which is quite fast compared with a conventional DPCM system.

In general, large errors are reduced quite fast, but small errors, which fortunately are much less disturbing, have a much slower decay. With a constant input signal even a permanent error at the decoder may remain after a transmission error. This can be understood by recalling that the PCM information in the transmitted hybrid D-PCM numbers  $N_h$  is coarsely quantized. When the output signal of the decoder is so close to the input signal of the encoder that both give rise to the same number  $N_f$  from the measurement with the coarse PCM scale FS, then no further error correction is performed

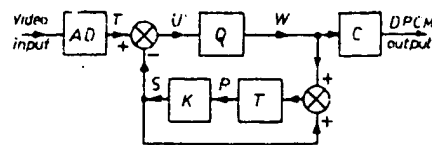


Fig. 5. Normal DPCM encoder with a leaking integrator (digital implementation). The input signal  $V_U$  of the quantizer  $Q$  is:

$$V_U = V_T - V_S = (V_T - V_R) + (1-k)V_R$$

AD = analog-to-digital converter (PCM).

$Q$  = quantizer.

$C$  = code converter.

$T$  = delay unit.

$K$  = multiplier.

until the input signal of the encoder varies so much that the numbers  $N_f$  in the encoder and in the decoder show a difference again.

A similar, generally concealed effect occurs in a digitally implemented usual DPCM system with leaking integrator (compare section 3) caused by rounding in the multiplier ( $K$  in fig. 5) or the succeeding subtractor.

It can be noted here that the error correcting property of the hybrid D-PCM decoder justifies the initial assumption in section 2.2, that the previous sample amplitude was decoded correctly. Any difference between the sample amplitude in the encoder and its reconstructed amplitude in the decoder will be corrected as if it were a transmission error.

### 2.4 The effects of limiting $N_d$

As indicated before, the desired limitation of the hybrid D-PCM number  $N_h$  from 0 to +7 is obtained by a suitable limitation of the DPCM number  $N_d$ . This means that the range of the possible levels on the difference scale DS is determined by the amplitude of the previous sample. If this previous sample has a low amplitude, the resulting PCM number  $N_f$  has a small value, so that only a small negative transition is possible but a much larger positive one. For instance sample  $S_3$  in fig. 3 gives rise to a PCM number  $N_f = 2$ , which allows the DPCM number  $N_d$  to acquire a value from -2 (small negative transition) up to +5 (large positive transition). Conversely, when the previous sample has a high amplitude, then only a small positive and a much larger negative transition are possible. So the hybrid D-PCM system provides an "automatic" adaptation of the range of the difference signal to the amplitude of the input signal. This is illustrated very clearly in figs. 3 and 4, where at each sample the allowed range for the coding of the next sample is indicated. The effect is similar to the result obtained with a switched quantizer [2], [3].

From the figs. 3 and 4 it also appears that a severe overload can occur when the input signal already has a rather low or a rather high amplitude (e.g.,  $N_f = 0; 1; 6$  and  $7$ ) and it shows a small transient to an even more extreme value. This effect can be improved by a better adaptation of the quantization characteristics of the scales FS and DS to each other, as in the first application described in section 4. Another possibility is to expand the scale FS to such an extent that the extreme numbers of FS (e.g.,  $N_f = 0; 1; 6$  and  $7$ ) are outside the amplitude range of the input signal, as in the second application in section 4. In the latter case some part of the adaptation of the range of the difference signal to the amplitude of the input signal is lost also, but still a considerable improvement with respect to conventional DPCM systems is preserved.



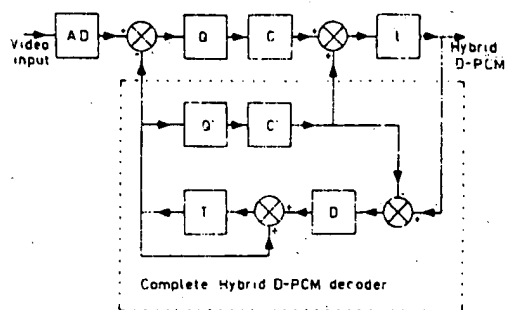


Fig. 9. Block diagram of a hybrid D-PCM encoder, containing a complete decoder and a limiter  $L$ .

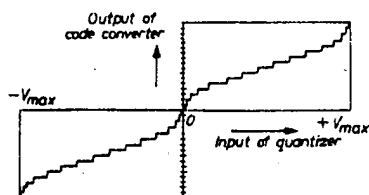


Fig. 10. Well-suited transfer characteristic for the quantizer and code converter of a hybrid D-PCM system.

block diagram of an implementation, that performs the desired limiting of  $N_h$  and that allows a complete freedom in the choice of the characteristics of  $Q$  and  $Q'$ . This is obtained by incorporating a complete decoder (compare fig. 8) in the feedback loop, so that an accumulation of the effects of limiter  $L$  is prevented.

#### 4. APPLICATIONS

Fig. 10 shows a type of transfer characteristic for the quantizer and code converter, that is very well suited for use in the hybrid D-PCM system. This type of quantizing characteristic has been proposed before by Bostelmann [4]. The advantages of his proposal are that no slope overload occurs and that in the transmission one bit is saved as compared with usual DPCM systems. If the transfer characteristics of the additional quantizer  $Q'$  and code converter  $C'$  in the hybrid D-PCM system (see fig. 7) are chosen to be equal to the positive part of the characteristics of the differential quantizer  $Q$  and code converter  $C$ , then exactly the same advantages are obtained as with Bostelmann's original proposal. This means also that the slope overload as described in section 2.4 is completely eliminated. Additionally, however, a fast error correction is obtained, which is shown in fig. 11. For an easy comparison, fig. 11 also shows the error responses of a usual DPCM system with an integrator with various leak factors  $k$  (see section 3).

From this example it will be clear that, with a suitable choice of the quantizing characteristics, the error performance of the hybrid D-PCM system is far superior to that of usual DPCM systems. Moreover, in contrast with systems with a leaking integrator, the hybrid D-PCM system does not increase the granular noise and contouring in flat areas of high or low signal values. In the example of fig. 11 it appears also that with a constant input signal a small steady state error may remain (compare with section 2.3). Computer simulation of the

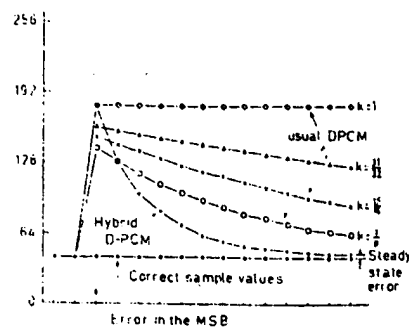


Fig. 11. Error correction of the hybrid D-PCM system with the characteristics of fig. 10, compared with usual DPCM systems.

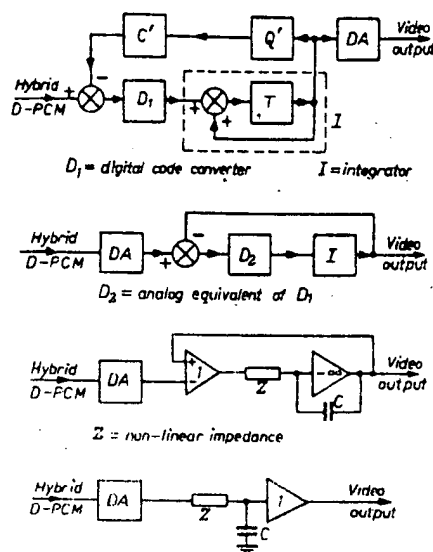


Fig. 12. Derivation of a hybrid D-PCM decoder with mainly analog signal processing from a fully digital decoder.

system has shown, however, that with a varying input signal the error is usually completely corrected within a few samples.

A second interesting application of the hybrid D-PCM system is a very simple encoder and decoder with mainly analog signal processing. Fig. 12 shows how an analog decoder can be derived from a fully digital decoder. First the digital-to-analog converter is moved from the output of the decoder to the front end, and a linear quantizing characteristic is chosen for the PCM feedback part. Next, the digital integrator is replaced by an analog one and the digital code converter  $D_1$  is replaced by its analog equivalent  $D_2$ . The third diagram of fig. 12 shows how in principle the functions of the second AD/I diagram can be implemented. The integrator consists of an operational amplifier with a feedback capacitor  $C$ .

Because the input of the operational amplifier is at virtual ground, the voltage across the nonlinear impedance  $Z$  is the voltage difference between the output of the DA converter and the video output. The current through  $Z$ , caused by this voltage difference, is integrated in the capacitor  $C$ . Finally the video output signal is put across the nonlinear impedance  $Z$  and the current through  $Z$  is integrated in the capacitor  $C$ .

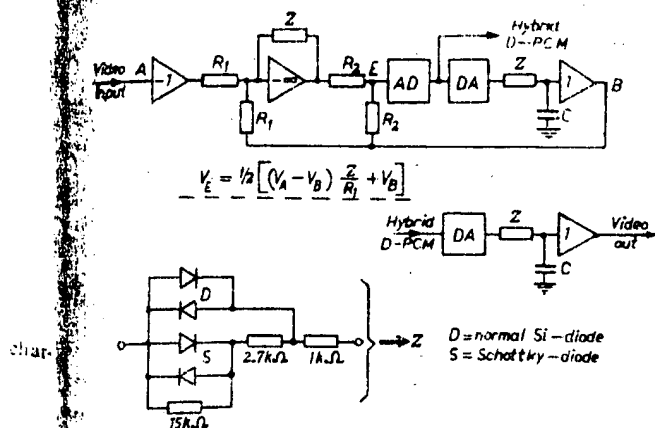


Fig. 13. Hybrid D-PCM encoder and decoder based on the decoder of fig. 12 and the encoder of fig. 9.

Fig. 13 shows how a hybrid D-PCM encoder can be made by embodying the analog decoder of fig. 12 in a feedback loop in a similar way as in fig. 9. The formula shows that the signal  $V_E$  at the input of the AD converter is indeed composed of the output signal  $V_B$  of the decoder (the amplitude of the previous sample) and the nonlinearly amplified difference signal  $(V_A - V_B)$ . For proper operation the AD and DA converter together ought to have a gain of two.

From these two applications it will be clear that the hybrid D-PCM system can be used for many types of predictive coders. Also for coders that use both horizontal and vertical prediction, the hybrid D-PCM system is able to reduce the probability of transmission errors considerably.

## 5. EXPERIMENTS

As a test for the hybrid D-PCM system the encoder and decoder of fig. 13 have been built. The actual implementation of the AD/DA converter combination has been inspired by the converter of [5] (fig. 7 in [5]) and for slowly varying input signals the operation of the circuit of fig. 13 shows a remarkable similarity to the corresponding part of the circuit in [5]. Actually fig. 5 of [5] holds identically for the hybrid D-PCM system of fig. 13. Only for transients in the input signal the nonlinearity of the impedances  $Z$  is important. The resistances in  $Z$  (lower part of fig. 13) determine the ratio of the small, medium, and large step sizes of the difference signal (scale DS or is a section 2) and the threshold voltages of the diodes determine the transitions between the different step sizes. The value of capacitor  $C$  depends on the sampling frequency of the AD/DA converter and it determines together with  $R_1$  (actually of an  $1\Omega$ ) the granular noise and transient response of the system.

In fig. 14 a picture is shown that has been encoded and decoded by the hybrid D-PCM system of fig. 12. The sample frequency chosen is 256 times the horizontal line frequency, error is usual with videophone systems, and 4 bits per sample are used.

The signal amplitude in the encoder has been adjusted such that only the eight levels in the center of the 4-bit AD converter are used for the coding of the previous sample amplitude  $V_B$ . This avoids the slope overload for small transients at the extreme signal amplitudes, as described in section 2.4. Due to



Fig. 14. Result of the encoding and decoding of a videophone picture with the hybrid D-PCM system of fig. 13.



Fig. 15. See fig. 14. The performance of the error correction is shown by introducing an inversion of the most significant bit at the same position in each line.

the automatic adaptation of the range of the difference signal to the level of the input signal, large and steep transients show no annoying slope overload. The effective range of the difference scale is about from  $-12$  to  $+12$ .

Fig. 15 shows the effect of a transmission error on the hybrid D-PCM system. At the same position in each line an inversion of the most significant bit has been introduced. It is obvious that these errors are rapidly corrected. The performance of the error correction is comparable with a usual DPCM system with an integrator time constant of about four sample periods. With the hybrid D-PCM system, however, no additional contouring and granular noise are introduced at all (see section 3).

## 6. CONCLUSION

The hybrid D-PCM system presented in this paper is a simple and very effective means of reducing the error sensitiv-



ity of predictive coders for television signals. This is achieved by a suitable incorporation of PCM information in the conventional difference code without increasing the bit rate. Moreover the automatic adaptation of the allowed range of the difference signal to the actual level of the input signal considerably reduces the slope overload of large steep transitions without increasing granular noise and contouring effects.

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## Autonomous Line Scanning for SPC Telephone Switching Systems

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**Abstract**—An Autonomous Line Scanning Unit (ALSU) for completely autonomous detection of call originations in the SPC Telephone Switching System is described. Through its own memories, ALSU maintains an up-to-date record of subscribers' statuses, detects call originations, performs 'hit timing check' and informs the Switching System of the identity of calling subscribers. The ALSU needs minimum interaction with the Central Processor, resulting in increased call handling capacity.

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## 1. INTRODUCTION

The Telephone Network of India, at the present stage, consists of electromechanical systems only. About 80% of subscribers are being served by automatic exchanges of Strowger or Crossbar types. Electronic Switching Systems are in an advanced stage of development. An experimental 100 line Stored Program Controlled (SPC) Electronic Telephone Exchange has been tried out successfully in the Telecommunication Research Centre of Indian P & T, and Indian Telephone Industries is manufacturing a 1000 line SPC Electronic Telephone Exchange for field trials. Telephone traffic in India has peculiar characteristics. The calling rate and average both ways traffic in some metropolitan areas may go as high as 16 Busy Hour Calls and 8.64 CCS (0.24 Erlang) per line. Telephone exchanges here are often subjected to very heavy traffic loads. Methods of increasing the call handling capacity of telephone switching systems, therefore, assume great importance in India. Enhancing call handling capacity of the system by changing the architecture of its Central Processor (CP) or by replacing the CP with a faster one would generally be more expensive than off-loading the CP of certain functions by using a front-end, special purpose processor. One such front-end processor or unit is described in this paper.

In a telephone exchange there are some functions of a routine nature which do not require flexibility. Such functions, done under the control of stored program, would add a considerable load to CP without really needing its intelligence [1, 2]. Detection of originating calls is one such function which can be done independently by an Autonomous Line Scanning Unit (ALSU) with its own wired logic control. Some form of Autonomous Scanning has been reported in the following systems:

- (a) No. 2 ESS (Bell System, USA) [3],
- (b) No. 4 ESS (Bell System, USA) [4],
- (c) AKE 132, Transit Exchange System (LM Ericsson, Sweden) [5],
- (d) SP-1, 4 Wire ESS (Northern Telecom Limited, Canada) [6],
- (e) PRX System (Philips, Holland) [7],
- (f) No. 1 FAX System (GTE Automatic Electric Inc., USA) [8],
- (g) KDX-0 System (Kokusai Denshin Denwo Co. Ltd., Nippon Electric Co. Ltd., Japan) [9],
- (h) System 250 (Plessey, England) [10].

These systems do not handle the complete process of originating call detection autonomously and substantial processor interaction is necessary in most of the cases. Characteristic features of ALSU that distinguish it from the systems mentioned above are: (i) Completely autonomous detection of call originations, (ii) 'Hit Timing Check' on detected originations without CP interaction, (iii) Listing of calling subscribers' identities within the unit for transfer to CP under interrupt, (iv) No need for CP to maintain a record of subscribers' statuses, since this can be obtained from the unit.

Concepts of the SPC Telephone Switching System (Fig. 1 [11-13]) may be recapitulated here for the sake of clarity. In this system, calls are processed by a CP which is a Stored Program

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